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Hybrid-Treemap Layouting

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Abstract

This paper presents an approach for hybrid treemaps, which applies and combines several different layout principles within a single tree map in contrast to traditional treemap variants based on a single layout concept. To this end, we analyze shortcomings of state-of-the-art treemap algorithms such as Moore, Voronoi and Strip layouts. Based on a number of identified edge cases, we propose a combination of these different layout algorithms, individually selected for and applied on each sub hierarchy of the given treemap data. The selection decision is based on the number of items to be layouted as well as the aspect ratio of the containing visual elements. Futhermore, a layout quality score based on existing treemap layout metrics (e.g., average distance change, relative direction change, average aspect ratio) has been used to evaluate the results of the proposed hybrid layout algorithm and to demonstrate its usefulness applied on representative hierarchical data sets.

Categories and Subject Descriptors (according to ACM CCS): [Human-centered computing]: Visualization—Treemaps; [Human-centered computing]: Visualization—Empirical studies in visualization

1. Introduction

Treemaps [JS91] serves as means to visualize hierarchical data sets in a scalable and space-filling way; they represent a research topic studied yet for more than two decades [Sch11]. Briefly, the visualization principle is based on representing a parent node by a finite area that is recursively subdivided into non-overlapping partitions used to visualize the child nodes. The size of the partitions depends on an application-specific defined weight, typically computed as per-node attribute data. The recursive subdivision follows a partition strategy known as *treemap layout*. Various layout algorithms have been published with several advantages and disadvantages with respect to their algorithmic complexity, the readability and the arrangement of the visual items in the resulting depictions [Sch11].

Besides other challenges, e.g., treemap rendering [THD13, WTLD15, LFH*16], or reduction of visual clutter [LSHD17], this paper focuses on using treemaps for data sets that change over time, e.g., for the visualization of software metric data [WL08, BD11] or business data [VvWVdL06], bringing up another challenge for the layout algorithm— the layout stability. The term *layout stability* refers to the ability of a layout algorithm to guarantee only small changes in the layout if only small changes in the data set occur [BSW02]. Among many advantages, stable layouts are essential for usability of treemap visualization because users may memorize the layout of treemaps. If small data changes would cause fundamental layout changes, users would have to rebuild their memorized treemap.

Many applications provide a collection of treemap layout algorithms. However, they apply only one (selected) treemap algorithm for visualizing the data. Frequently, this results in several edge cases decreasing the layout quality, e.g., using a squarified treemap layout [BHVW00] for a large number of items within a narrow parent element results in highly narrow items.

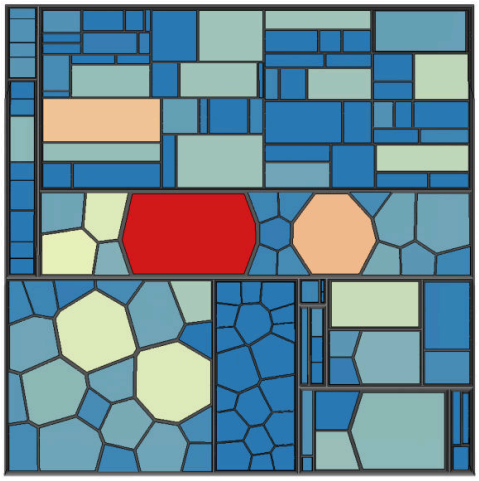


Figure 1: *A Hybrid-treemap layout algorithm using a combination of* Moore*,* Slice'n'Dice*,* Strip *and* Voronoi *treemaps.*

In this paper, we propose a *hybrid treemap layout* that selects and applies several different treemap layouts for each sub hierarchy of

the given data set within a single treemap visualization (Figure 1). The hybrid layout algorithm takes into account the aspect ratio of the parent's representation and the number of items to be layouted. To test and evaluate the approach, we generated a large number of artificial data sets with only one hierarchy level and produced a series of snapshots representing changed data sets over time (e.g., revisions). The data sets serve as input for eight different treemap layout algorithms to create a decision-tree for the proposed hybrid treemap layout. Exisiting layout quality measurements [BSW02, HBD17] (*average aspect ratio*, *average distance change*, *relative direction change*) were used to determine a *layout quality score* for the evaluation of the test datasets.

This paper is organized as follows. Section 2 gives a brief overview about related work in the field of treemap layout algorithms as well as layout quality metrics. The used input data for generating the decision tree and the layout metric results are discussed in Section 3. The hybrid treemap layout approach is presented in Section 4. An evaluation of the presented layout based on test data sets is described in Section 5. The paper concludes with a discussion and an outlook on future work in Section 6.

2. Related Work

Treemap Layout Algorithms are published for more than two decades [Sch11]. Johnson and Shneiderman presented the initial *Slice'n dice treemap (1991)* that uses a subdivision in either horizontal or vertical direction, alternating based on the depth of a hierarchical element [JS91]. This approach, especially if used for sub-hierarchies with a large number of items, results in shapes with high aspect-ratios and, therefore, poor readability. Bruls et al. put a high focus on readability with *Squarified treemaps (2000)*, using a treemap algorithm that creates square-like shapes and, hence, it allows for average aspect ratios near one, but as a trade-off shows poor layout stability [BHVW00]. The trade-off between nicely-shaped regions and layout stability was first mentioned by Bederson et al., introducing the *Strip treemap (2002)* and a first evaluation that takes into account the change of positions for varying hierarchical data sets [BSW02]. Tu and Shen tried to overcome the challenge of layout instability by using a spiral-shaped space-filling curve, *Spiral treemap (2007)* [TS07], that also allows for preserving a specific order of data in the depiction. Tak and Cockburn [TC13] also use a space-filling curve to compute the initial item positions; their *Hilbert & Moore treemaps (2013)* creates low mean aspect-ratio and good stability. They also introduced a new layout metric, the *location drift*, which overcomes some of the disadvantages of the distance change metric. Nevertheless, the evaluation of this algorithm against other common ones did not consider hierarchical data sets. In addition to the common rectangular treemap approaches, Balzer and Deussen present generalized Voronoi- (or Power-)diagrams to create *Voronoi treemaps (2005)*, using random initial positions for items [BD]. The algorithm was extended by Hahn et al. to allow for stable distributions, resulting in treemaps that create items with low average aspect ratios and a high visual stability [HTMD14].

Layout Stability in Treemaps is highly connected to the research in mental maps. Misue et al. define the mental map for graphs with a model consisting of three different aspects: orthogonal *ordering*, *proximity relations*, and *topology* [MELS95]. Their definition of topology focuses on the connections between graph nodes is not directly applicable to implicit hierarchical visualization techniques like treemaps. Nevertheless, the orthogonal ordering and proximity relations propose a direction on how to evaluate the changes in a layout with respect to a user's mental map. A common metric for evaluating treemap layout stability is the *average distance change* introduced by Bederson et al. [BSW02], which only takes into account the change in the Euclidean distance of the absolute position and aspect ratios of depicted items. Several evaluations were performed showing that their respective layout algorithm performs best with respect to layout stability. However, either they introduced algorithm specific metrics or used artificial or non-hierarchical data sets [BSW02, TS07, TC13]. Kong et al. evaluate as a prerequisite for a good area estimation in treemaps, the rule of nicely-shaped regions and item orientations [KHA10]. In a controlled experiment they found, that users can hardly estimate high aspect ratios especially with different orientations. Hahn et al. present the *relative direction change*, metric that focuses on the topology and arrangement of treemap items and show that a combination of average aspect ratio, average distance change and relative direction can serve as significant parameters for a prediction model for user behavior in treemap item recovering tasks [HBD17].

3. Design Decisions

The design decisions for the hybrid treemap layouting are based on observations from multiple measurements with single-level treemaps. These observations as well as the input datasets for the treemaps are explained in detail in this section.

3.1. Generated Datasets

The generated data, that serves as the input for the treemap layout algorithms consists of multiple varying datasets. For a better understanding we refer to the following terminology:

- **Snapshot:** A single-level (one parent, multiple children) hierarchical dataset with an additional numeric attribute. This attribute is percentage-wise expressed through the area of the treemap items with respect to the sum of all items.
- **Time-line:** A group of snapshots with a starting snapshot and multiple successor snapshots extracted by changing the predecessor to a certain degree. Each time-line has a starting point given by a static number of child (*childNumber* items created.
- **Time-line group:** A group of time-lines with the same starting point (*childNumber*).

The numeric attribute values and their changes were created according to [TC13]. Also, the time-lines include the deletion and adding of items on a five percent chance to create more realistic datasets. Due to this, the *childNumber* of a snapshot just refers to its starting number of children, while the actual number of children can increase or decrease within the time-line (no snapshots with less than 2 items were used). The complete input data for the computed treemaps contained 20 time-line groups with starting child number from two to 500 items (2-10, 12, 15, 17, 20, 25, 35, 50, 75, 100, 250, 500). Each time-line group contained 10 different time-lines with each 100 snapshots. This results in 20.000 data snapshots as an input for 8 different treemap algorithms.

3.2. Layout Metrics

Eight different treemap layouts for (*Slice'n'Dice, Strip, StripInverted, Squarified, Spiral, Moore, Hilbert, Voronoi*) have been implemented. For each treemap the layout metrics were computed for the aforementioned single-level datasets (see Section 3.1). In addition to the varying number of child elements, 13 different aspect ratios for the parent element were used, from wide to narrow base elements ($\frac{1}{10}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{9}{10}$, $\frac{1}{1}$, $\frac{10}{9}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{2}{1}$, $\frac{4}{1}$, $\frac{10}{1}$).

Using these factors (*childNumber* and *aspectRatio*) three layout-quality metrics were measured:

- **Average Distance Change:** Position changes of each individual treemap items.
- **Relative Direction Change:** Changes of a treemap's topology (arrangement and adjacency of treemap items).
- **Average Aspect Ratio:** Reflecting the readability and usefulness of the treemap.

Finally, the average of all three metrics was used to create a *layout quality score*. Since all metrics aim for a low number (a 1.0 reflects high changes), a lower quality score indicates less change and small aspect ratios.

3.3. Layout Quality Results

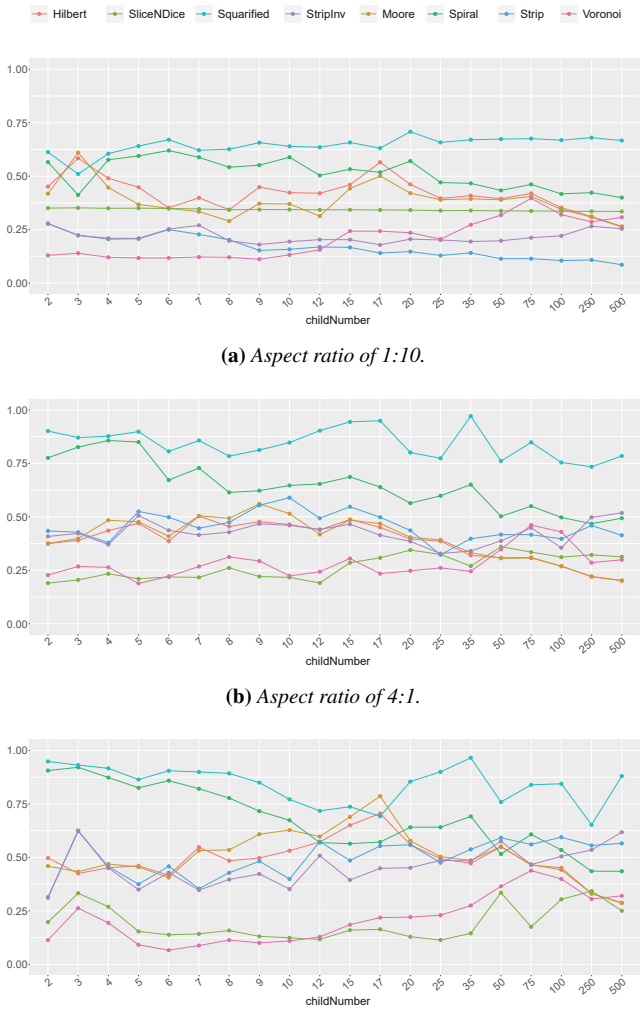
For the final results all trials from a time-line group (same *childNumber*) were aggregated after a normalization for each algorithm. The 2.080 aggregated measurements (13 *aspectRatio* $\times$ 20 *childNumber* $\times$ 8 *layouts*) and their resulting layout quality score show several patterns:

- Moore treemaps perform best for aspect-ratios from $\frac{1}{2}$ to $\frac{2}{1}$
- Moore treemaps almost always perform equal or better than Hilbert tremaps (243 of 260 measurements)
- Squarified treemaps seem insufficient for all cases, Spiral treemaps perform just slightly better than Squarified
- Narrow treemap items (up to an aspect ratio of $\frac{1}{2}$) should be layouted as Strip (Figure 2a)
- Wide treemap items (starting from an aspect ratio of $\frac{4}{1}$) should be layouted as Slice'n'Dice treemaps (Figure 2b & 2c)
- Very narrow treemap items (up to an aspect ratio of $\frac{1}{4}$) with small amount of children (up to 12) should be layouted with Voronoi treemaps (Figure 2a)
- Wide treemap items (starting from an aspect ratio of $\frac{2}{1}$) with less than 50 children should be layouted with Voronoi treemaps
- Very wide treemap items (starting from an aspect ratio higher than $\frac{4}{1}$) can be layouted with Voronoi treemaps as an alternative to Slice'n'Dice treemaps (Figure 2c)

The complete decision tree extracted from the results is described in detail in Section 4.

4. Hybrid-Treemap Algorithm

Using the results from Section 3.3 a hybrid treemap algorithm was implemented. Mixing traditional rectangular-treemap approaches with polygonal approaches, such as *Voronoi* treemaps, introduces one major prerequisite. Since a space-filling rectangular subdivision of an arbitrary shaped polygon is not possible, a polygonal approach can only be applied if the hierarchical item that is layouted either does not contain any sub-hierarchies (leafs only), or every sub-hierarchy is also layouted as a *Voronoi* treemap. In this approach, we decided that sub-hierarchies with leaf nodes only are possible candidates for *Voronoi* treemap layouts to allow for a higher flexibility in the decision for each individual sub-hierarchy. As pointed out in Section 3, *Moore* treemaps generally serve as a favorable layout algorithm within a wide range of aspect ratios. To keep the number of layout switches as low as possible, the decision tree is mainly focused on a few edge-cases (Figure 3).



(a) *Aspect ratio of 1:10.*

(b) *Aspect ratio of 4:1.*

(c) *Aspect ratio of 10:1.*

Figure 2: *Measurements for 3 out of 13 different aspect ratios (2a, 2b, 2c) of the generated datasets showing the layout quality score (y-axis) in relation to* childNumber *(x-axis).*

5. Evaluation

A quantitative evaluation was performed to investigate the performance of the presented hybrid-treemap layout approach with respect to the aforementioned layout quality score. For it, the file

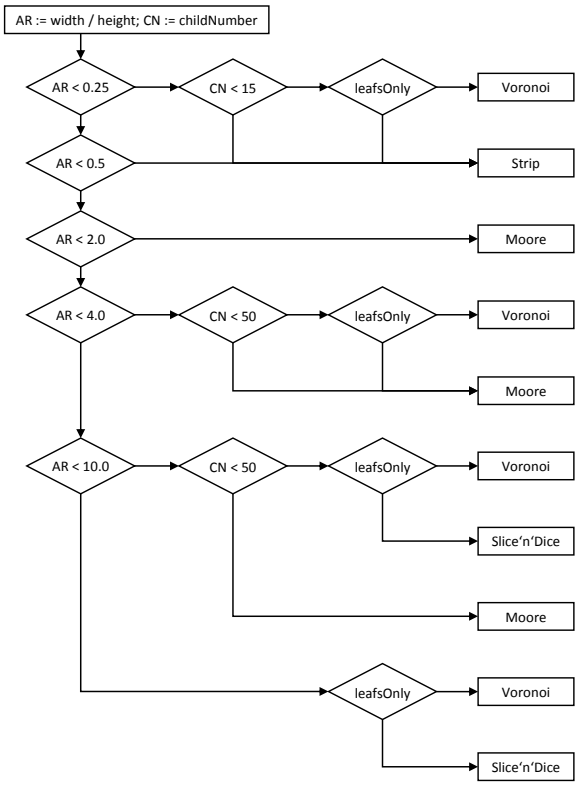


Figure 3: *The flow diagram showing the decision tree for the implemented* Hybrid *treemap layout. Arrows leaving the right side of decisions (diamonds) represent the* `True` *branch while leaving the bottom represents the* `False` *branch.*

structures and development histories of eleven software systems (extracted from public github repositories) were used. The projects were randomly picked from a large base of software system data. In addition to the file structure of these systems, the number of lines-of-codes (LoC) of each file serves as the associated numeric attribute, mapped to the area of the treemap items. Futhermore, the used datasets contained multiple snapshots (min: 17, max: 28) of the file structure from different points in time. The characteristic of the snapshots with respect to the number of elements varied from very small, but fastly evolving (*Deeplearning4j* - min: 16, max: 1035) to large stable ones (*Qt* - around 20k each). All snapshots were generated at an interval of one month for each project. A precheck guaranteed that there have been changes between each consecutive snapshot. Also, in contrast to the trials from Section 3, we did not include *Slice'n'Dice* treemaps in the final comparison, due to its bad readability for complete real-life datasets.

The used datasets shows hybrid treemaps performed slightly better ($Mean = .258$, $sd = .126$) than other layout algorithms (e.g., Spiral: $Mean = .286$, $sd = .181$) for the tested datasets (Figure 4). Additionally, we found that *Moore* treemaps ($Mean = .294$, $sd = .137$) performed better than *Hilbert* treemaps ($Mean = .352$, $sd = .109$). While *Strip* and *StripInverted* treemaps show highly similar performance, *Squarified* treemap achieves worse layout quality scores than all other rectangular approaches ($Mean = .507$, $sd = .236$). In contrast to the scores from the generated dataset trials, *Voronoi* treemaps perform poorly for the chosen datasets ($Mean = .640$, $sd = .010$).

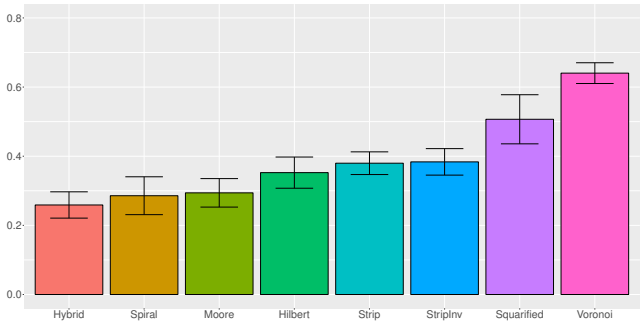


Figure 4: *Aggregated average results of the final evaluation from eleven real-life datasets with standard error. A smaller score indicates a better layout quality with respect to stability and aspect ratio average.*

6. Conclusion

We presented a treemap layout that combines the strength of several state-of-the-art treemap approaches. At the same time, the hybrid algorithm makes use of a decision tree which reduces weak-spots of treemap algorithms when used in static manner. An evaluation with real-life datasets shows the usefulness (in terms of a layout quality score) of this approach.

Even though, the hybrid treemap algorithm works sufficient for hierarchical datasets with different characteristics, there is a lot of possibility for improvements. First, decision tree, only based on one data characteristic (the number of elements to be layouted) and a layout attribute (the aspect ratio), is very simple. A more sophisticated decision could be achieved if multiple data characteristics, e.g., changes appearing on the structure or the numeric attributes, of the evolving hierarchical dataset are taken into account. Second, the hard decisions used by this approach are possible weak spots of the algorithm itself. If a sub-hierarchy is changed by an increasing or decreasing number of items and steps over the threshold, a complete change of the sub-hierarchy layout is happening.

Further investigation in the decision process of which treemap layout to use is needed and will be done as future work. Additionally, datasets from alternative domains (other than software systems) will be used for the more detailed information.

The complete supplemental material to this paper is available here

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References

[BD] BALZER M., DEUSSEN O.: Voronoi treemaps. In *Proceedings of the IEEE Symposium on Information Visualization (InfoVis'05)*, pp. 49–56. 2

[BD11] BOHNET J., DÖLLNER J.: Monitoring code quality and development activity by software maps. In *Proceedings of the 2nd Workshop on Managing Technical Debt* (2011), ACM, pp. 9–16. 1

[BHVW00] BRULS M., HUIZING K., VAN WIJK J. J.: Squarified treemaps. In *Proceedings of the Joint Eurographics and IEEE TCVG Symposium on Visualization* (2000), Springer, pp. 33–42. 1, 2

[BSW02] BEDERSON B. B., SHNEIDERMAN B., WATTENBERG M.: Ordered and quantum treemaps: Making effective use of 2d space to display hierarchies. *AcM Transactions on Graphics (TOG) 21*, 4 (2002), 833–854. 1, 2

[HBD17] HAHN S., BETHGE J., DÖLLNER J.: Relative direction change: A topology-based metric for layout stability in treemaps. In *Proceedings of the 8th International Conference of Information Visualization Theory and Applications (IVAPP'17)* (2017), pp. 88–95. 2

[HTMD14] HAHN S., TRÜMPER J., MORITZ D., DÖLLNER J.: Visualization of varying hierarchies by stable layout of voronoi treemaps. In *Proceedings of the 5th International Conference of Information Visualization Theory and Applications (IVAPP'14)* (2014), pp. 50–58. 2

[JS91] JOHNSON B., SHNEIDERMAN B.: Tree-maps: A space-filling approach to the visualization of hierarchical information structures. In *Proceedings of the IEEE Conference on Visualization* (1991), IEEE, pp. 284–291. 1, 2

[KHA10] KONG N., HEER J., AGRAWALA M.: Perceptual guidelines for creating rectangular treemaps. *IEEE Transactions on Visualization and Computer Graphics 16*, 6 (2010), 990–998. 2

[LFH*16] LIMBERGER D., FIEDLER C., HAHN S., TRAPP M., DÖLLNER J.: Evaluation of sketchiness as a visual variable for 2.5d treemaps. In *Proceedings of the 20th International Conference of Information Visualization (IV'16)* (2016). 1

[LSHD17] LIMBERGER D., SCHEIBEL W., HAHN S., DÖLLNER J.: Reducing visual complexity in software maps using importance-based aggregation of nodes. In *Proceedings of the 8th International Conference on Information Visualization Theory and Applications (IVAPP'17)*. 2017, pp. 176–185. 1

[MELS95] MISUE K., EADES P., LAI W., SUGIYAMA K.: Layout adjustment and the mental map. *Journal of visual languages and computing 6*, 2 (1995), 183–210. 2

[Sch11] SCHULZ H.-J.: Treevis. net: A tree visualization reference. *Computer Graphics and Applications, IEEE 31*, 6 (2011), 11–15. 1, 2

[TC13] TAK S., COCKBURN A.: Enhanced spatial stability with hilbert and moore treemaps. *IEEE Transactions on Visualization and Computer Graphics 19*, 1 (2013), 141–148. 2

[THD13] TRAPP M., HAHN S., DÖLLNER J.: Interactive rendering of complex 3d-treemaps. In *Proceedings of the 8th International Conference on Computer Graphics Theory and Applications (GRAPP'13)* (2013), pp. 165–175. 1

[TS07] TU Y., SHEN H.-W.: Visualizing changes of hierarchical data using treemaps. *IEEE Transactions on Visualization and Computer Graphics 13*, 6 (2007), 1286–1293. 2

[VvWVdL06] VLIEGEN R., VAN WIJK J. J., VAN DER LINDEN E.-J.: Visualizing business data with generalized treemaps. *IEEE Transactions on Visualization and Computer Graphics 12*, 5 (2006), 789–796. 1

[WL08] WETTEL R., LANZA M.: Codecity: 3d visualization of large-scale software. In *Proceedings of the 30th international conference on Software engineering* (2008), ACM, pp. 921–922. 1

[WTLD15] WÜRFEL H., TRAPP M., LIMBERGER D., DÖLLNER J.: Natural phenomena as metaphors for visualization of trend data in interactive software maps. In *Computer Graphics and Visual Computing (CGVC)* (2015). 1